OPEN-FILE REPORT 98-20

SEISMIC HAZARD EVALUATION OF THE LOS ANGELES 7.5-MINUTE QUADRANGLE, LOS ANGELES COUNTY, CALIFORNIA

1998

MINES AND GEOLOGY
CALIFORNIA CONSERVATION

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

DIVISION OF MINES AND GEOLOGY
JAMES F. DAVIS, *STATE GEOLOGIST*

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PREFACE

With the increasing public concern about the potential for destructive earthquakes in northern and southern California, the State Legislature passed the Seismic Hazards Mapping Act in 1990. The purpose of the Act is to protect the public from the effects of strong ground shaking, liquefaction, landslides or other ground failure, and other hazards caused by earthquakes. The program and actions mandated by the Seismic Hazards Mapping Act closely resemble those of the Alquist-Priolo Earthquake Fault Zoning Act (which addresses only surface fault-rupture hazards) and are outlined below:

1. **The State Geologist** is required to delineate the various "seismic hazard zones."

2. **Cities and Counties**, or other local permitting authorities, must regulate certain development "projects" within the zones. They must withhold the development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans.

3. **The State Mining and Geology Board (SMGB)** provides additional regulations, policies, and criteria to guide cities and counties in their implementation of the law. The SMGB also provides criteria for preparation of the Seismic Hazard Zone Maps (Web site http://www.consrv.ca.gov/dmg/shezp/zoneguid/) and for evaluating and mitigating seismic hazards.

4. **Sellers (and their agents)** of real property within a mapped hazard zone must disclose at the time of sale that the property lies within such a zone.

As stated above, the Act directs the State Geologist, through the Division of Mines and Geology (DMG) to delineate seismic hazard zones. Delineation of seismic hazard zones is conducted under criteria established by the Seismic Hazards Mapping Act Advisory Committee and its Working Groups and adopted by the California SMGB.

The Official Seismic Hazard Zone Maps, released by DMG, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available from:

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Seismic Hazard Evaluation Reports, released as Open-File Reports (OFR), summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These Open-File Reports are available for reference at DMG offices in Sacramento, San Francisco, and Los Angeles. Copies of the reports may be purchased at the Sacramento, Los Angeles, and San Francisco offices. In addition, the Sacramento office offers prepaid mail order sales for all DMG OFRs. **NOTE: The Open-File Reports are not available through BPS Reprographic Services.**

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Seismic Hazard Evaluation Reports and additional information on seismic hazard zone mapping in California are available on the Division of Mines and Geology's Internet homepage:
http://www.consrv.ca.gov/dmg/shezp/

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed DMG to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that the 1) process for zoning liquefaction hazards remain unchanged and that 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Evaluation Report summarizes the development of the hazard zone map for each area. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historic high-water-table information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Los Angeles 7.5-Minute Quadrangle (scale 1:24,000).

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Los Angeles 7.5-Minute Quadrangle, Los Angeles County, California

By

Elise Mattison and Ralph C. Loyd

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also on the Internet at http://www.consrv.ca.gov/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Los Angeles 7.5-minute Quadrangle (scale 1:24,000). This section and Section 2 addressing earthquake-induced landslides, are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazards zone mapping in California can be accessed on DMG's World Wide Web page: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Liquefaction-induced ground failure has historically been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes, significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles area was caused by liquefaction-induced ground displacement.

Loose, water-saturated granular sediments within 40 feet of the ground surface underlie localities most susceptible to liquefaction-induced damage. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the opportunity for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in general, as well as in the Los Angeles Quadrangle.

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils is generally confined to areas covered by Quaternary sedimentary deposits. Such areas consist mainly of alluviated valleys, floodplains, and canyon regions. The evaluation is based on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth data, most of which are gathered from a variety of sources. The quality of the data used varies. Although the selection of data used in this evaluation was rigorous, the State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth and thickness of liquefiable sediments, depth to ground water, rate of drainage, slope gradient, proximity to free-face conditions, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to determine the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction potential, opportunity, and susceptibility, and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The heavily urbanized Los Angeles Quadrangle encompasses about 60 square miles in central Los Angeles County and includes all or parts of the cities of Alhambra, Bell, Commerce, Glendale, Los Angeles, Montebello, Monterey Park, Pasadena, San Marino, South Pasadena, and Vernon, as well as some unincorporated areas of Los Angeles County. The Elysian Hills, situated in the west-central part of the quadrangle, rise to an elevation of 640 feet, nearly 400 feet above downtown Los Angeles. To the north and east are the Repetto Hills that culminate in Mt. Washington at 846 feet, the highest point in the quadrangle. The southern fringe of the San Rafael Hills lies at the northern margin of the Los Angeles Quadrangle. The Los Angeles River flows through a narrow floodplain between the hills and continues southward across the Los Angeles Basin. Arroyo Seco cuts through the Repetto Hills and joins the Los Angeles River at the base of the Elysian Hills near Glendale Junction. Farther south and east are the Laguna Channel and Coyote Pass drainages. The southern third of the quadrangle consists of gentle to moderately sloping alluviated surfaces with drainage channels running generally in a south-southwestward direction.

GEOLOGIC CONDITIONS

Surface Geology

A Quaternary geologic map of the Los Angeles Quadrangle (Yerkes, 1997) was obtained in digital form from the U.S. Geological Survey (USGS). Additional sources of geologic information used in this evaluation include Tinsley and Fumal (1985) and Dibblee (1989). DMG staff modified mapped contacts between alluvium and bedrock and remapped the Quaternary units in more detail. Stratigraphic nomenclature was revised to follow the format developed by the Southern California Areal Mapping Project (SCAMP) (Morton and Kennedy, 1989). The revised geologic map used in this study is included as Plate 1.1.

About one-fourth of the Los Angeles Quadrangle is covered by Holocene alluvial sediments (Plate 1.1). These younger Quaternary alluvial fan units are exposed within and adjacent to the present and past courses of the Los Angeles River and its tributaries. Holocene sediments also occur as thin surficial deposits in the Repetto Hills. Other map units in the quadrangle include extensive exposures of Pleistocene alluvium, Tertiary marine sedimentary rocks exposed in the Elysian, Repetto, and San Rafael hills, and a small pre-Tertiary basement-rock exposure in the northwest corner (Section 2 of this report).

Subsurface Geology and Geotechnical Characteristics

Borehole logs from subsurface investigations within the Los Angeles Quadrangle were collected at the California Department of Transportation (CalTrans); the California Regional Water Quality

Control Board, Los Angeles Region; DMG environmental review and hospital review projects, private consultants and the U.S. Geological Survey (USGS). The USGS supplied copies of paper logs collected from the Los Angeles County Department of Public Works storm drain investigations.

Borehole log selection focused on, but was not limited to, boreholes in Quaternary sedimentary deposits. Lithologic, soil test, and related data reported in the logs from 281 boreholes were entered into the DMG geographic information system (GIS) database. Many of the remaining logs were reviewed during this investigation to aid with statigraphic correlation. Locations of all exploratory boreholes in the database are shown on Plate 1.2.

Computer-constructed cross sections enabled staff to relate soil-engineering properties to various depositonal units, correlate soil types from one borehole to another, and extrapolate geotechnical data into outlying areas containing similar soils. Evaluation of borehole logs shows that young Quaternary sediments are dominated by loose to moderately dense sand in the northern part of the quadrangle and loose to moderately dense sand and silt in the southern part. Only a few thin clay layers were reported in boreholes penetrating Holocene sediments throughout the Los Angeles Quadrangle.

GROUND-WATER CONDITIONS

Seismic hazard zoning for liquefaction focuses on areas historically characterized by ground water depths of 40 feet or less. Accordingly, a ground water evaluation was performed in the Los Angeles Quadrangle to determine the presence and extent of historical shallow ground water. Data required to conduct the evaluation were obtained from technical publications, geotechnical boreholes, and water-well logs dating back to the early 1900's (Mendenhall, 1908; Conkling, 1927). The depths to first-encountered water free of piezometric influences were plotted and hand contoured on a computer- generated map (Plate 1.2). The resultant map was compared to other similar published maps as a check against any major discrepancies (Tinsley and others, 1985; Leighton and Associates, 1990; Los Angeles City, 1996).

Historical shallow water was mapped in the northwest quarter and along the south-central and northern margins of the Los Angeles Quadrangle. Shallow water at the southern border of the Los Angeles Quadrangle extends into the South Gate Quadrangle (Pridmore, in press). Shallow ground water also exists in Arroyo Seco, the Los Angeles River floodplain north of the downtown Los Angeles area, and canyons draining the Elysian Hills and Repetto Hills in the northern half of the quadrangle. In drainages, sediments on shallow and impermeable bedrock collect water and can remain saturated for long periods, especially during wet seasons.

PART II

EVALUATING LIQUEFACTION POTENTIAL

Liquefaction occurs in water saturated sediments during moderate to great earthquakes. Liquefied sediments are characterized by a loss of strength and may fail, causing damage to buildings, bridges, and other such structures. A number of methods for mapping liquefaction hazard have been proposed; Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of susceptibility units, and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce liquefaction potential. Liquefaction susceptibility is a function of the capacity of sediments to resist liquefaction and liquefaction opportunity is a function of the seismic ground shaking intensity. The application of the Seed Simplified Procedure (Seed and Idriss, 1971) for evaluating liquefaction potential allows a quantitative characterization of susceptibility of geologic units. Tinsley and others (1985) apply a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for mapping liquefaction hazards in the Los Angeles region. The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985), combining geotechnical data analyses, and geologic and hydrologic mapping, but follows criteria adopted by the California State Mining and Geology Board (in press).

LIQUEFACTION OPPORTUNITY

According to the criteria adopted by the California State Mining and Geology Board (in press), liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for ground shaking strong enough to generate liquefaction. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% probability of exceedance over a 50-year period. The earthquake magnitude is the magnitude that contributes most to the acceleration.

For the Los Angeles Quadrangle, peak accelerations of 0.44 g to 0.65 g resulting from earthquakes of magnitude 6.4 to 7.0 were used for liquefaction analyses. The PGA and magnitude values were derived from maps prepared by Petersen and others (1996) and Cramer and Petersen (1996), respectively. See the ground motion portion (Section 3) of this report for further details.

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of soils to loss of strength when subjected to ground shaking. Primarily, physical properties and conditions of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance. Soils that lack resistance (susceptible soils) are typically saturated, loose sandy sediments. Soils resistant to liquefaction include all soil types that are dry or sufficiently dense. Cohesive soils are generally not considered susceptible to liquefaction.

DMG's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil-property and soil-condition factors such as type, age, texture, color, and consistency, along with historic depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, findings can be related to the map units. A qualitative susceptible soil inventory is outlined below and summarized in Table 1.1.

Pleistocene deposits (Qof)

Based on the generally high blow counts recorded on the borehole logs, as well as the qualitative description of the materials as dense to very dense sand, silt, and gravel, the older Quaternary alluvial fan deposits in the Los Angeles Quadrangle are not considered to be potentially liquefiable.

Holocene deposits (Qyf, Qw)

Holocene deposits in the Los Angeles Quadrangle consist largely of sand and silt along with lesser amounts of gravel and clay. Logs of most test boreholes drilled into these young Quaternary units report loose to moderately dense sand. Where saturated within 40 feet of the ground surface (Plate 1.2), these sedimentary units are judged susceptible to liquefaction.

Map Unit	Age	Environment of Deposition	Primary Textures	General Consistency	Susceptible to Liquefaction?*
Qw	Historical	Active stream channels	Sand, gravel, cobbles	Loose	Yes
Qyf	Holocene	Alluvial fans	Sand, silt, gravel	Loose to medium dense	Yes
Qof	Pleistocene	Alluvial fans	Sand, silt, gravel	Dense to very dense	Not likely

*when saturated

Table 1.1. General geotechnical characteristics and liquefaction susceptibility of Quaternary alluvial fan and wash deposits in the Los Angeles Quadrangle.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; Seed and Harder, 1990; Youd and Idriss, 1997). This procedure calculates soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR) based on standard penetration test (SPT) results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses, expressed in terms of cyclic stress ratio (CSR). The factor of safety (FS) relative to liquefaction is: FS=CRR/CSR. FS, therefore, is a quantitative measure of liquefaction potential. Generally, a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, indicates the presence of potentially liquefiable soil. DMG uses FS, as well as other considerations such as slope, free face conditions, and thickness and depth of potentially liquefiable soil, to construct liquefaction potential maps, which then directly translate to Zones of Required Investigation.

Of the 281 borehole logs in the Los Angeles Quadrangle (Plate 1.2), 117 include blow-count data from SPTs or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2 1/2-inch inside diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. Few borehole logs, however, include all of the information (soil density, moisture content, sieve analysis, etc.) required for an ideal Seed Simplified Analysis. For boreholes having acceptable penetration tests, liquefaction analysis is performed using logged density, moisture, and sieve test values, or using average test values of similar materials.

LIQUEFACTION ZONES

Criteria for Zoning

The areas underlain by late Quaternary geologic units were included in liquefaction zones using the criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the California State Mining and Geology Board (in press). Under those criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historic earthquakes.

2. All areas of uncompacted fills containing liquefaction susceptible material that are saturated, nearly saturated, or may be expected to become saturated.

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable.

4. Areas where existing geotechnical data are insufficient.

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historic high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (between 11,000 years and 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historic high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria for liquefaction zoning in the Los Angeles Quadrangle is summarized below.

Areas of Past Liquefaction

Historical liquefaction has not been reported in the Los Angeles Quadrangle, nor is there any known evidence of paleoseismic liquefaction. Therefore, no areas within the Los Angeles Quadrangle are zoned for potential liquefaction based on historic liquefaction.

Artificial Fills

Non-engineered artificial fills have not been delineated or mapped in the Los Angeles Quadrangle. Consequently, no such areas within the Los Angeles Quadrangle are zoned for potential liquefaction based on their presence.

Areas with Sufficient Geotechnical Data

Borehole logs, which generally included limited penetration test data and reasonably sufficient lithologic descriptions, were used to determine the high liquefaction susceptibility ratings assigned sediments deposited in the Los Angeles River and Arroyo Seco floodplains, and some lesser drainages. Accordingly, these areas are included in zones of required investigation based on adequate geotechnical data.

Areas of Insufficient Geotechnical Data

Younger alluvium deposited in canyon and incised channel areas generally lack adequate geotechnical borehole information. The soil characteristics and ground-water conditions in these cases are assumed to be similar to deposits where subsurface information is available. The canyon and incised stream channel deposits, therefore, are included in the liquefaction zone for reasons presented in criterion 4a above.

ACKNOWLEDGMENTS

The authors thank the staff of the California Departments of Transportation (CalTrans) and Water Resources and the California Regional Water Quality Control Board–Los Angeles Region. John Tinsley of the U.S. Geological Survey graciously shared information from his extensive files of subsurface geotechnical data. We give special thanks to Siang Tan and Pamela Irvine for geological mapping; Bob Moskovitz, Teri McGuire, and Scott Shepherd of DMG for their GIS operations support; and Barbara Wanish for graphic layout and reproduction of Seismic Hazard Zone maps.

REFERENCES

California State Mining and Geology Board, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Department of Conservation, Division of Mines and Geology, Special Publication 117, 74 p.

California State Mining and Geology Board, in press, Criteria for delineating seismic hazard zones: California Department of Conservation, Division of Mines and Geology, Special Publication 118, 21 p.

Conkling, Harold, 1927, San Gabriel investigation: California Department of Public Works, Division of Water Rights, Bulletin 5, 640 p.

Cramer, C.H., and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange, and Ventura counties, California: Bulletin of Seismological Society of America, v. 86, no. 5, p. 1,645-1,649.

Dibblee, T.W., Jr., 1989, Geologic map of the Los Angeles Quadrangle, Los Angeles County, California: Dibblee Geological Foundation Map DF-22, Santa Barbara California, scale 1:24,000.

Leighton and Associates, Inc., 1990, Hazard reduction in Los Angeles County: Technical Appendix to the Safety Element of the Los Angeles County General Plan, Department of Regional Planning, County of Los Angeles, 2 v.

Los Angeles City, 1996, Proposed safety element of the Los Angeles City General Plan, 55 p.

Mendenhall, W.C., 1908, Ground waters and irrigation enterprises in the foothill belt, southern California: U.S. Geological Survey Water-Supply Paper No. 219, 180 p.

Morton, D.M. and Kennedy, M.P., 1989, A southern California digital 1:100,000-scale geologic map series—The Santa Ana Quadrangle—The first release: Geological Society of America Abstracts with Programs v. 21, no. 6, p. A107-A108.

Petersen, M.D. and Cramer, C.H., 1997, Assessing earthquake ground shaking hazard in California: California Geology, v. 50, no. 4, p. 107-115.

Petersen, M.D., Cramer, C.H., Bryant, W.A., Reichle, M.S. and Toppozada, T.R., 1996, Preliminary seismic hazard assessment for Los Angeles, Ventura, and Orange counties, affected by the 17 January 1994 Northridge earthquake: Bulletin of the Seismological Society of America, v. 86, no. 1B, p. S247-S261.

Pridmore, C.L., in press, Liquefaction zones in the South Gate 7.5-minute quadrangle, Los Angeles County, California, *in* Seismic hazard evaluation of the South Gate 7.5-minute quadrangle, Los Angeles County, California: California Department of Conservation, Division of Mines and Geology Open-File Report 98-25, Part 1; plate scale 1:48,000.

Seed, R.B. and Harder, L.F., 1990, SPT-based analysis of cyclic pore pressure generation and undrained residual strength: Proceedings of the H. Bolton Seed Memorial Symposium, v. 2, p. 351-376.

Seed, H.B. and Idriss, I.M., 1971, Simplified procedure for evaluating soil liquefaction potential: Journal of the Soil Mechanics and Foundations Division of American Society of Civil Engineers, v. 97: SM9, p. 1,249-1,273.

Seed, H.B., Idriss, I.M. and Arango, Ignacio, 1983, Evaluation of liquefaction potential using field performance data: Journal of Geotechnical Engineering, v. 109, no. 3, p. 458-482.

Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

Tinsley, J.C. and Fumal, T.E., 1985, Mapping Quaternary sedimentary deposits for areal variations in shaking response, *in* Ziony, J. I., *editor*, Evaluating earthquake hazards in the Los Angeles Region—An earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 101-125.

Tinsley, J.C., Youd, T.L., Perkins, D.M. and Chen, A.T.F., 1985, Evaluating liquefaction potential, *in* Ziony, J.I., *editor*, Evaluating earthquake hazards in the Los Angeles region—An earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 263-315.

Yerkes, R.F., 1997, Preliminary geologic map of the Los Angeles 7.5’ quadrangle, Southern California: U.S. Geological Survey Open File Report 97-254, 9 p., scale 1:24,000.

Youd, T.L., 1991, Mapping of earthquake-induced liquefaction for seismic zonation: Earthquake Engineering Research Institute, Proceedings, Fourth International Conference on Seismic Zonation, v. 1, p. 111-138.

Youd, T.L. and Idriss, I.M., 1997, *editors*, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: National Center for Earthquake Engineering Research, Technical Report NCEER-97-0022, 276 p.

Youd, T.L. and Perkins, D.M. 1978, Mapping liquefaction-induced ground failure potential: Journal of Geotechnical Engineering, v. 104, p. 433-446.

SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Los Angeles 7.5-Minute Quadrangle, Los Angeles County, California

By

Michael A. Silva, Pamela J. Irvine, and Siang S. Tan

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Los Angeles 7.5-minute Quadrangle (scale 1:24,000). This section and Section 1 addressing liquefaction, are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Landslides triggered by earthquakes have historically been a major cause of earthquake damage. Landslides triggered by the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes were responsible for destroying or damaging numerous homes and other structures, blocking major transportation corridors, and damaging various types of life-line infrastructure. Typically, areas most susceptible to earthquake-induced landslides are on steep slopes and on or adjacent to existing landslide deposits, especially if the earth materials in these areas are composed of loose colluvial soils, or poorly cemented or highly fractured rock. These geologic and terrain conditions exist in many parts of southern California, most notably in hilly areas already developed or currently undergoing development. In addition, the opportunity for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region, which includes the Los Angeles Quadrangle.

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered primarily from a variety of outside sources; thus the quality of the data is variable. Although the selection of data used in this evaluation was rigorous, the state of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Earthquake-generated ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. No attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Los Angeles Quadrangle, for more information on the delineation of liquefaction zones.

Information developed in the study is presented in two parts: physiographic, and geologic conditions in PART I, and ground shaking opportunity, landslide hazard potential and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The heavily urbanized Los Angeles Quadrangle encompasses about 60 square miles in central Los Angeles County and includes all or parts of the cities of Alhambra, Bell, Commerce, Glendale, Los Angeles, Montebello, Monterey Park, Pasadena, San Marino, South Pasadena, and Vernon, as well as some unincorporated areas of Los Angeles County. The Elysian Hills, situated in the west-central part of the quadrangle, rise to an elevation of 640 feet, nearly 400 feet above downtown Los Angeles. To the north and east are the Repetto Hills that culminate in Mt. Washington at 846 feet, the highest point in the quadrangle. The southern fringe of the San Rafael Hills lies at the northern margin of the Los Angeles Quadrangle. The Los Angeles River flows through a narrow floodplain between the hills and continues southward across the Los Angeles Basin. Arroyo Seco cuts through the Repetto Hills and joins the Los Angeles River at the base of the Elysian Hills near Glendale Junction. Farther south and east are the Laguna Channel and Coyote Pass drainages. The southern third of the quadrangle consists of gentle to moderately sloping alluviated surfaces with drainage channels running generally in a south-southwestward direction.

GEOLOGIC CONDITIONS

Surface and Bedrock Geology

A recently compiled U.S. Geological Survey (USGS) geologic map was obtained in digital form (Yerkes, 1997) for the Los Angeles Quadrangle. The contacts between bedrock and alluvium from the digital file were extensively modified to conform to the topographic contours of the USGS 7.5-minute quadrangle. The Quaternary units were remapped by Tan (unpublished) to include more detail and to be consistent with the units mapped in the adjacent El Monte Quadrangle. Bedrock geology was also modified to reflect more recent mapping. In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to development and abundance of landslides was noted.

The oldest geologic unit mapped in the Los Angeles Quadrangle is the Cretaceous Wilson Quartz Diorite (wqg), a medium- to coarse-grained biotite-hornblende quartz diorite that is massive to poorly foliated. A small outcrop of this unit is exposed in the northwest corner of the quadrangle.

The southern part of the San Rafael Hills and northern part of the Repetto Hills are primarily composed of marine clastic sedimentary rocks of the middle Miocene Topanga Formation. In this area, the Topanga Formation consists of medium- to coarse-grained, locally conglomeratic sandstone (Tt1), massive to well-bedded conglomerate with a basal breccia (Tt2), and well-bedded siltstone with interbedded sandstone, shale, and chert (Tt3).

The eastern Elysian Park Hills and central Repetto Hills are composed of deep-marine clastic and biogenic rocks of the upper Miocene Puente Formation. These rocks consist of interbedded and interfingering siltstone and fine sandstone (Tpn1), shale and siltstone (Tpn2), diatomaceous shale and siltstone (Tpn3), and fine- to coarse-grained, thinly laminated to thick-bedded sandstone (Tpn4).

Marine and nonmarine clastic sedimentary rocks of the Pliocene Fernando Formation overlie the Puente Formation in the Repetto Hills and southernmost Elysian Park Hills. The Fernando Formation locally consists of conglomerate and coarse-grained conglomeratic sandstone (Tf1), massive, soft, micaceous, very fine- to medium-grained sandstone (Tf2), and massive, soft, micaceous siltstone with local layers of pebbly sandstone (Tf3).

Quaternary sediments covering the remainder of the Los Angeles Quadrangle include older and younger alluvial-fan deposits (Qof and Qyf), modern alluvial wash deposits (Qw), and modern lacustrine deposits (Ql). Numerous landslide deposits (Qls and Qls?) are present on the steeper slopes in the Repetto Hills area. The majority of these slope failures occurred in interbedded shale, siltstone, and sandstone of the Puente Formation and soft, micaceous siltstone of the Fernando Formation. A more detailed discussion of the Quaternary deposits in the Los Angeles Quadrangle can be found in Section 1.

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, they must first be ranked on the basis of their overall shear strength. The primary source for rock shear-strength measurements is geotechnical reports prepared by consultants, on file with local government permitting departments. Shear strength data for the rock units identified on the geologic map were obtained from the City of Los Angeles, Department of Public Works (see Appendix A). The locations of rock and soil samples taken for shear testing are shown on Plate 2.1.

Shear strength data gathered from the above source were compiled for each mapped geologic unit, and subdivided for fine-grained and coarse-grained lithologies if appropriate. Geologic units were grouped on the basis of average angle of internal friction (average f) and lithologic character. When available, shear tests from adjacent quadrangles were used to augment data for geologic formations that had little or no shear test information. No shear tests were available for Tf?, Tf1, Tf2, Tt2, wqg, and the various subdivisions of the Quaternary alluvial units, except Qya1 and Qya2. These geologic units were added to existing groups on the basis of lithologic and stratigraphic similarities.

To subdivide mapped geologic formations that have both fine-grained and coarse-grained lithologies, we assumed that where stratigraphic bedding dips into a slope (favorable bedding) the coarse-grained material strength dominates, and where bedding dips out of a slope (adverse bedding) the fine-grained material strength dominates. We then used structural information from the geologic map (see “Structural Geology”) and terrain data in the form of slope gradient and aspect, to identify areas with a high potential for containing adverse bedding conditions. These areas, located on the map, were then used to modify the geologic material-strength map to reflect the anticipated lower shear strength for the fine-grained materials.

The results of the grouping of geologic materials in the Los Angeles Quadrangle are in Tables 2.1 and 2.2.

LOS ANGELES QUADRANGLE
SHEAR STRENGTH GROUPS

	Formation Name	Number Tests	Mean/Median Phi	Mean/Median (Group phi) (deg)	Group Mean/Median C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analysis
GROUP 1	Tpn1(fbc)	10	36.5/37			Tt2	
	Tpn2(fbc)	20	35.6/36	35/35	410/350	wqg	35
	Tt3(fbc)	10	35.6/36				
	Tpn4(fbc)	26	33.7/32				
GROUP 2	Tt1	24	30.2/31			All Q	
	Qya2	10	30.2/31			Tf?	
	Qya1	13	29.8/31			Tf1	
	Tpn2(abc)	30	28.8/29	28.4/28	523/500	Tf2	28.4
	Tt3(abc)	20	28.5/29				
	Tpn4(abc)	6	27.5/25.5				
	Tf3	36	27.3/27				
	Tpn1(abc)	26	26.8/27.5				
GROUP 3	Tpn3	11	23.8/24	23.8/24	368/200		23.8
GROUP 4	Qls	-	-	-	-	-	15

abc= adverse bedding condition, fine-grained material strength
fbc = favorable bedding condition, coarse-grained material strength

Table 2.1. Summary of the shear strength statistics for the Los Angeles Quadrangle.

SHEAR STRENGTH GROUPS FOR THE LOS ANGELES QUADRANGLE

GROUP 1	GROUP 2	GROUP 3	GROUP 4
Tpn1(fbc)	All Q	Tpn3	Qls
Tpn2(fbc)	Tf?		
Tpn4(fbc)	Tf1		
Tt2	Tf2		
Tt3(fbc)	Tf3		
wqg	Tf3?		
	Tpn1(abc)		
	Tpn2(abc)		
	Tpn4(abc)		
	Tt1		
	Tt3(abc)		

(abc) adverse bedding conditions, fine grained material
(fbc) favorable bedding conditions, coarse grained material

Table 2.2. Summary of the shear strength groups for the Los Angeles Quadrangle.

Structural Geology

Accompanying the digital geologic map (Yerkes, 1997) were digital files of associated geologic structural data, including bedding and foliation attitudes (strike and dip) and fold axes. We used the structural geologic information provided with the digital geologic map (Yerkes, 1997) and from Dibblee (1991) to categorize areas of common stratigraphic dip direction and magnitude, similar to the method presented by Brabb (1983). The dip direction category was compared to the slope aspect (direction) category and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude category was less than or equal to the slope gradient category, and the bedding dip was greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area. This information was then used to subdivide mapped geologic units into areas where fine-grained and coarse-grained strengths would be used.

Landslide Inventory

The evaluation of earthquake-induced landsliding requires an up-to-date and complete picture of the previous occurrence of landsliding. An inventory of existing landslides in the Los Angeles Quadrangle was prepared (Tan, unpublished) by combining field observations, analysis of aerial photos, and interpretation of landforms on current and older topographic maps. The following aerial photos were used for landslide interpretation: Fairchild (1927), Fairchild (1973), and USGS (1994). Also consulted during the mapping process were previous maps and reports that contain geologic and landslide data (Dibblee, 1989; Harp and Jibson, 1995; Hsu, 1982; Lamar, 1970;

Schoellhamer and others, 1954; Weber and others, 1979, Weber, 1980; and Weber and others, 1980). The completed hand-drawn landslide map was scanned, digitized, and the database was attributed with information on confidence of interpretation (definite, probable, or questionable) and other properties, such as activity, thickness, and associated geologic unit(s). A version of this landslide inventory is included with Plate 2.1.

PART II

EARTHQUAKE-INDUCED LANDSLIDE GROUND SHAKING OPPORTUNITY

Design Strong-Motion Record

The Newmark analysis used in delineating the earthquake-induced landslide zones requires the selection of a design earthquake strong-motion record. For the Los Angeles Quadrangle, the selection was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by DMG for a 10% probability of being exceeded in 50 years (Petersen and others, 1996; Cramer and Petersen, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.6 to 7.0
Modal Distance:	2.5 to 7.5 km
PGA:	0.42 to 6.4 g

The strong-motion record selected was the Channel 3 (north horizontal component) University of Southern California Station #14 recording from the magnitude 6.7 Northridge earthquake (Trifunac and others, 1994). This record had a source to recording site distance of 8.5 km and a PGA of 0.69 g. The selected strong-motion record was not scaled or otherwise modified prior to analysis.

Displacement Calculation

To develop a relationship between the yield acceleration (a_y; defined as the horizontal ground acceleration required to cause the factor of safety to equal 1.0) and Newmark displacements, the design strong-motion record was integrated twice for a given a_y to find the corresponding displacement, and the process repeated for a range of a_y (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for any combination of geologic material strength and slope angle, as represented by the yield acceleration. We used displacements of 30, 15 and 5 cm as criteria for rating levels of earthquake shaking damage on the basis of the work of Youd (1980), Wilson and Keefer (1983), and the DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.076, 0.129 and 0.232 g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant to the Los Angeles Quadrangle.

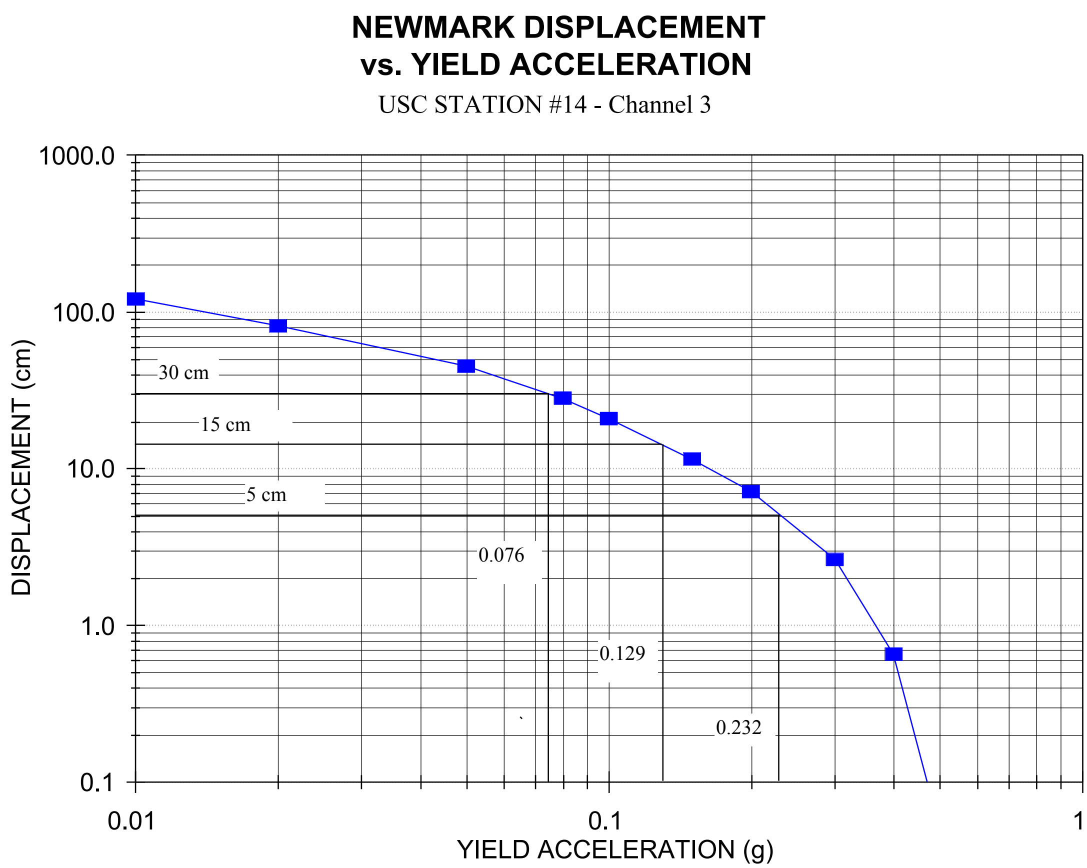

Figure 2.1. Yield acceleration vs. Newmark displacement for the USC Station #14 strong-motion record from the 17 January 1994 Northridge, California Earthquake.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. To calculate slope gradient for the terrain within the Los Angeles Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, which was prepared from the 7.5-minute quadrangle contours, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy. A program that adds a pixel to the edges of the DEM was run twice to avoid the loss of data at the quadrangle edges when the slope calculations were performed. A peak and pit smoothing process was then performed to remove errors in the elevation points.

To update the terrain data to reflect areas that have recently undergone large-scale grading, one graded area in the hilly portion of the Los Angeles Quadrangle was identified. Terrain data for this area were obtained from an airborne interferometric radar (TOPSAR) DEM flown and processed in August 1994 by NASA's Jet Propulsion Laboratory (JPL), and processed by Calgis, Inc. (GeoSAR Consortium, 1995; 1996). These terrain data were also smoothed and filtered prior to analysis. Plate 2.1 shows the area where the topography is updated to 1994 grading conditions.

A slope map was made from both the USGS DEM and the radar DEM using a third-order, finite difference, center-weighted algorithm (Horn, 1981). The USGS DEM was then used to make a slope-aspect map. The USGS slope map was used in conjunction with the aspect map and geologic structural data to identify areas of potential adverse bedding conditions. Both slope maps were used with the geologic strength map, reflecting graded and ungraded conditions, in the preparation of the earthquake-induced landslide hazard potential map.

Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where FS is the Factor of Safety, g is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield acceleration calculated by Newmark's equations represents the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. The acceleration values were compared with the ground shaking opportunity, defined by Figure 2.1, to determine the earthquake-induced landslide hazard potential. Based on the criteria described in Figure 2.1 above, if the calculated yield acceleration was less than 0.076 g, expected displacements could be greater than 30 cm, and a HIGH (H on Table 2.3) hazard potential was assigned. Likewise, if the calculated a_y fell between 0.076 and 0.129 g a MODERATE (M on Table 2.3) hazard potential was assigned, between 0.129 and 0.232 a LOW (L on Table 2.3) potential was assigned, and if a_y were greater than 0.232 g a VERY LOW (VL on Table 2.3) potential was assigned.

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

LOS ANGELES QUADRANGLE
HAZARD POTENTIAL MATRIX

SLOPE CATEGORY (% SLOPE)

Geologic Material Group	MEAN PHI	I 0-7%	II 7-12%	III 12-21%	IV 21-30%	V 30-36%	VI 36-40%	VII 40-46%	VIII 46-55%	IX 55-62%	X >62%
1	35	VL	VL	VL	VL	VL	VL	VL	L	M	H
2	28.4	VL	VL	VL	VL	L	L	M	H	H	H
3	23.8	VL	VL	VL	L	M	H	H	H	H	H
4	15	L	M	H	H	H	H	H	H	H	H

Table 2.3. Hazard potential matrix for earthquake-induced landslides in the Los Angeles Quadrangle. Shaded area indicates hazard potential levels included within the hazard zone.

EARTHQUAKE-INDUCED LANDSLIDE ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (in press). Under those criteria, earthquake-induced landslide zones are areas meeting one or more of the following:

1. Areas known to have experienced earthquake-induced slope failure during historic earthquakes.

2. Areas identified as having past landslide movement, including both landslide deposits and source areas.

3. Areas where CDMG's analyses of geologic and geotechnical data indicate that the geologic materials are susceptible to earthquake-induced slope failure.

Existing Landslides

Studies of the types of landslides caused by earthquakes (Keefer, 1984) show that re-activation of the whole mass of deep-seated landslide deposits is rare. However, it has been observed that the steep scarps and toe areas of existing landslides, which formed as a result of previous landslide movement, are particularly susceptible to earthquake-induced slope failure. In addition, because they have been disrupted during landslide movement, landslide deposits are inferred to be weaker than coherent, undisturbed, adjacent source rocks. Finally, we felt that a long duration, San Andreas fault-type earthquake could be capable of initiating renewed movement in existing deep-seated landslide deposits. Therefore, all existing landslides identified in the inventory with a definite or probable confidence of interpretation were included in the hazard zone.

During the course of this study, no Northridge earthquake-triggered landslides were identified in the Los Angeles Quadrangle (Harp and Jibson, 1995).

Geologic and Geotechnical Analysis

On the basis of a DMG pilot study (McCrink and Real, 1996) the earthquake-induced landslide zone includes all areas determined to lie within the High, Moderate and Low levels of hazard potential. Therefore, as shown in Table 2.3, geologic strength group 4 is always included in the zone (mapped landslides): strength group 3 materials are included in the zone for all slope gradients above 21%; strength group 2 materials are included in the zone for slope gradients above 30%; and strength group 1 materials, the strongest rock types, are zoned for slope gradients above 46%. This results in roughly 5% of the land in the quadrangle lying within the hazard zone.

ACKNOWLEDGMENTS

The authors would like to thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project. Geologic material strength data were collected at the City of Los Angeles with the assistance of Nicki Girmay. Digital terrain data were provided by Randy Jibson of the U.S. Geological Survey. Technical review of the methodology was provided by Bruce Clark, Randy Jibson, Robert Larson, Scott Lindvall, and J. David Rogers, who are members of the State Mining and Geology Board's Seismic Hazards Mapping Act Advisory Committee Landslides Working Group. At DMG, special thanks to Bob Moskovitz, Teri McGuire, Scott Shepherd and Barbara Wanish for their GIS operations support, to Lisa Chisholm for inputting the landslide attribute data into Excel, and to Barbara Wanish for designing and plotting the graphic displays associated with the Hazard Zone Map and this report. Assistance in the application of the radar DEM was provided by Rick Wilson and Tim McCrink.

REFERENCES

Brabb, E.E., 1983, Map showing direction and amount of bedding dip of sedimentary rocks in San Mateo County, California: U.S. Geological Survey Miscellaneous Investigations Series Map I-1257C, 1 sheet, scale 1:62,500.

California State Mining and Geology Board, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Department of Conservation, Division of Mines and Geology, Special Publication 117, 74 p.

California State Mining and Geology Board, in press, Criteria for delineating seismic hazard zones: California Department of Conservation, Division of Mines and Geology, Special Publication 118, 21 p.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange and Ventura counties, California: Bulletin of the Seismological Society of America, v. 85, no. 5, pp. 1645-1649.

Dibblee, T.W., Jr., 1989, Geologic map of the Los Angeles Quadrangle, Los Angeles County, California: Dibblee Geological Foundation Map #DF-22, scale 1:24,000.

GeoSAR Consortium, 1995, Year 1: Research and development status report for GeoSAR, a radar-based terrain mapping project: U.S. Government's Advanced Research Projects Agency Contract Order No. B335/00, 135 p.

GeoSAR Consortium, 1996, Year 1: Research and development status report for GeoSAR, a radar-based terrain mapping project: U.S. Government's Advanced Research Projects Agency Contract Order No. B378/00, 70 p.

Harp, E.L. and Jibson, R.W., 1995, Inventory of landslides triggered by the 1994 Northridge, California earthquake: U.S. Geological Survey Open-File Report 95-213, 17 p., Plate 1 scale 1:100,00; Plate 2 scale 1:50,000.

Horn, B.K.P., 1981, Hill shading and the reflectance map: Proceedings of the IEEE, v. 69, no. 1, p. 14-47.

Hsu, E.Y., 1982, Investigation and inventory of slope failures that occurred in 1978 and 1980 in the Los Angeles 7.5'-minute quadrangle, Los Angeles County, California: California Division of Mines and Geology Open-File Report 82-26, 60 p., Plates 1 and 2 scale 1:24,000.

Jibson, R.W., 1993, Predicting earthquake-induced landslide displacements using Newmark's sliding block analysis: Transportation Research Board, National Research Council, Transportation Research Record 1411, 17 p.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, no. 4, p. 406-421.

Lamar, D.L., 1970, Geology of the Elysian Park-Repetto Hills area, Los Angeles County, California: California Division of Mines and Geology Special Report 101, 45 p., Plate 1 scale 1:24,000.

McCrink, T.P. and Real, C.R., 1996, Evaluation of the Newmark method for mapping earthquake-induced landslide hazards in the Laurel 7-1/2 minute Quadrangle, Santa Cruz County, California: California Division of Mines and Geology Final Technical Report for U.S. Geological Survey Contract 143-93-G-2334, U.S. Geological Survey, Reston, Virginia, 31 p.

Newmark, N.M., 1965, Effects of earthquakes on dams and embankments: Geotechnique, v. 15, no. 2, p. 139-160.

Petersen, M.D., Cramer, C.H., Bryant, W.A., Reichle, M.S., and Toppozada, T.R., 1996, Preliminary seismic hazard assessment for Los Angeles, Ventura, and Orange counties, California, affected by the January 17, 1994 Northridge earthquake: Bulletin of the Seismological Society of America, v. 86, no. 1B, p. S247-S261.

Schoellhamer, J.E., Vedder, J.G., and Yerkes, R.F., 1954, Geology of the Los Angeles basin: California Division of Mines Bulletin 170, Chapter II, Cont. 5, Plate 1 scale 1:97,000.

Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

Tan, S.S., unpublished, Landslide inventory of the Los Angeles 7.5-minute Quadrangle, Los Angeles County, California.

Trifunac, M.D., Todorovska, M.I., and Ivanovic, S.S., 1994, A note on distribution of uncorrected peak ground accelerations during the Northridge, California earthquake of 17 January 1994: Soil Dynamic and Earthquake Engineering, v. 13, no. 3, p. 187-196.

U.S. Geological Survey, 1993, Digital Elevation Models: National Mapping Program, Technical Instructions, Data Users Guide 5, 48 p.

Weber, F.H., Jr., 1980, Landsliding and flooding in southern California during the winter of 1979-80: California Division of Mines and Geology Open-File Report 80-3, 69 p.

Weber, F.H., Jr., Bennett, J.H., Chapman, R.H., Chase, G.W., and Saul, R.B., 1980, Earthquake hazards associated with the Verdugo-Eagle Rock and Benedict Canyon fault zones, Los Angeles County, California: California Division of Mines and Geology Open-File Report 80-10.

Weber, F.H., Jr., Treiman, J.A., Tan, S.S., and Miller, R.V., 1979, Landslides in the Los Angeles region, California: effects of the February-March rains: California Division of Mines and Geology Open-File Report 79-4, 277 p., scale 1:250,000.

Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, earthquake: Bulletin of the Seismological Society of America, v. 73, p. 863-877.

Yerkes, R.F., 1997, Preliminary geologic map of the Los Angeles 7.5' Quadrangle, southern California: U.S. Geological Survey Open File Report 97-254, scale 1:24,000.

Youd, T.L., 1980, Ground failure displacement and earthquake damage to buildings: American Society of Civil Engineers Conference on Civil Engineering and Nuclear Power, 2d, Knoxville, Tennessee, 1980, v. 2, p. 7-6-2 to 7-6-26.

AIR PHOTOS

Fairchild Aerial Surveys, 1927, Aerial photography, Flight 113, Frames 297-310, 351-364, 387-404, black and white, vertical, scale 1:19,000.

Fairchild Aerial Surveys, Flight 7300, January 23, 1973, Frames 20-24 to 20-31, 21-25 to 21-33, 22-27 to 22-32, black and white, vertical, scale 1:26,000.

U.S. Geological Survey NAPP Aerial Photography, Flight 6858, May 31, 1994, Frames 62-64, 66-67, 87-91, black and white, vertical, scale 1:40,000.

APPENDIX A

SOURCES OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
City of Los Angeles, Department of Building and Safety	224
City of Monterey Park	18
Total Number of Shear Tests Collected	242

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Los Angeles 7.5-Minute Quadrangle, Los Angeles County, California

By

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included, are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5- minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the "Simple

Prescribed Parameter Value" method (SPPV) described in the site investigation guidelines (California State Mining and Geology Board, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2, addressing liquefaction and earthquake-induced landslide hazards, constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the seismogenic sources as published in the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology, and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10% probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

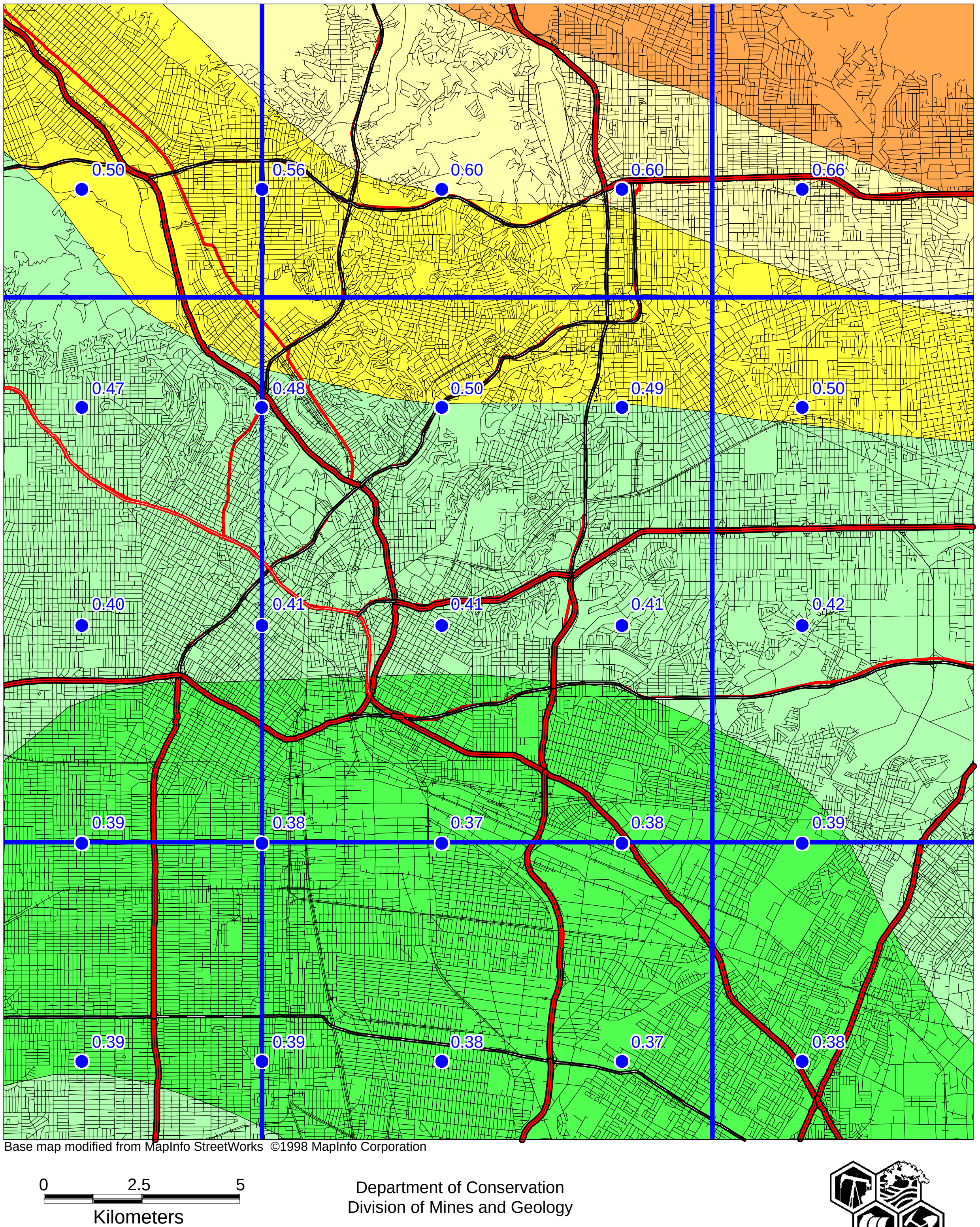
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

LOS ANGELES 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



Department of Conservation
Division of Mines and Geology

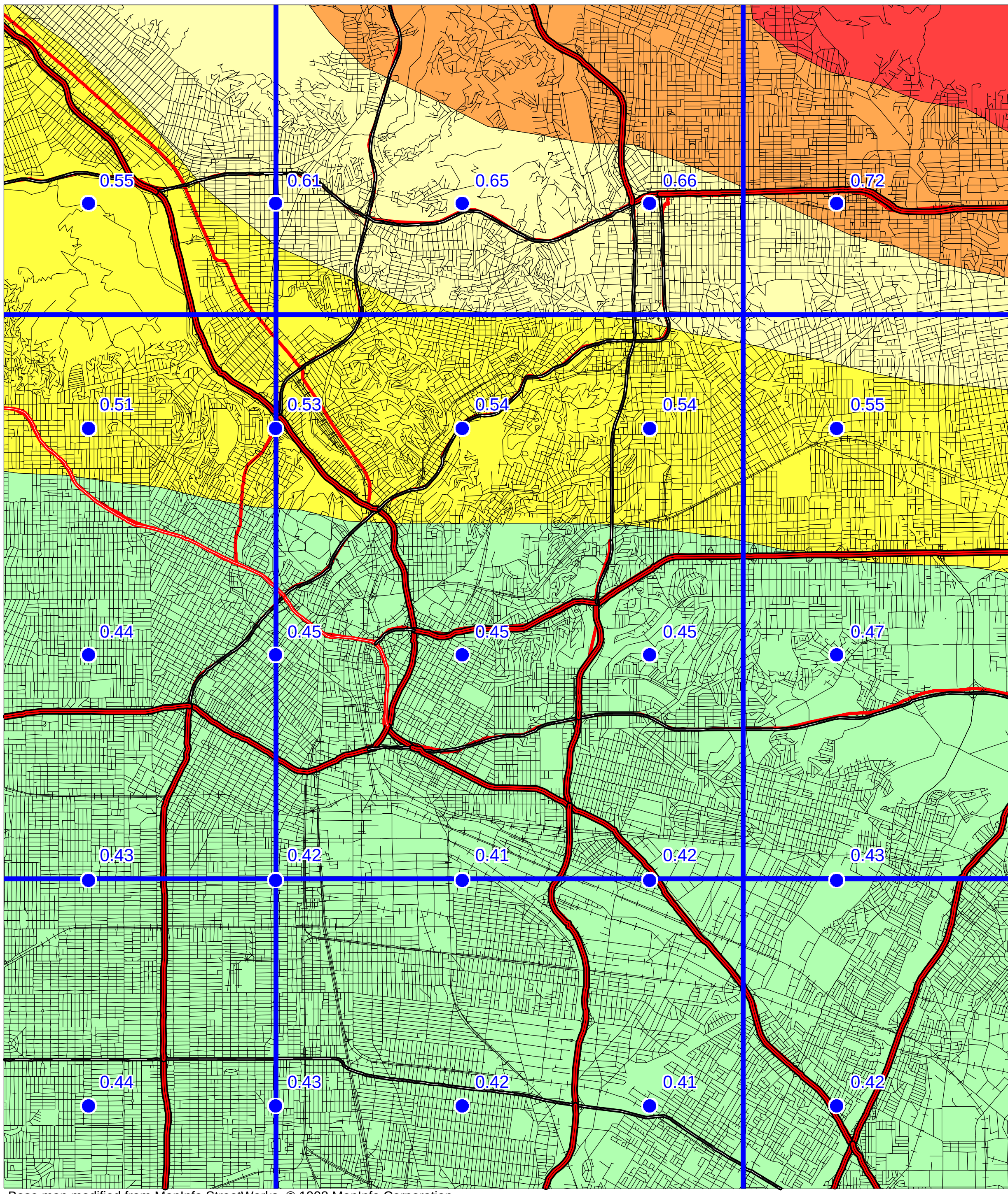
Figure 3.1

LOS ANGELES 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 2.5 5

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Figure 3.2

LOS ANGELES 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

ALLUVIUM CONDITIONS

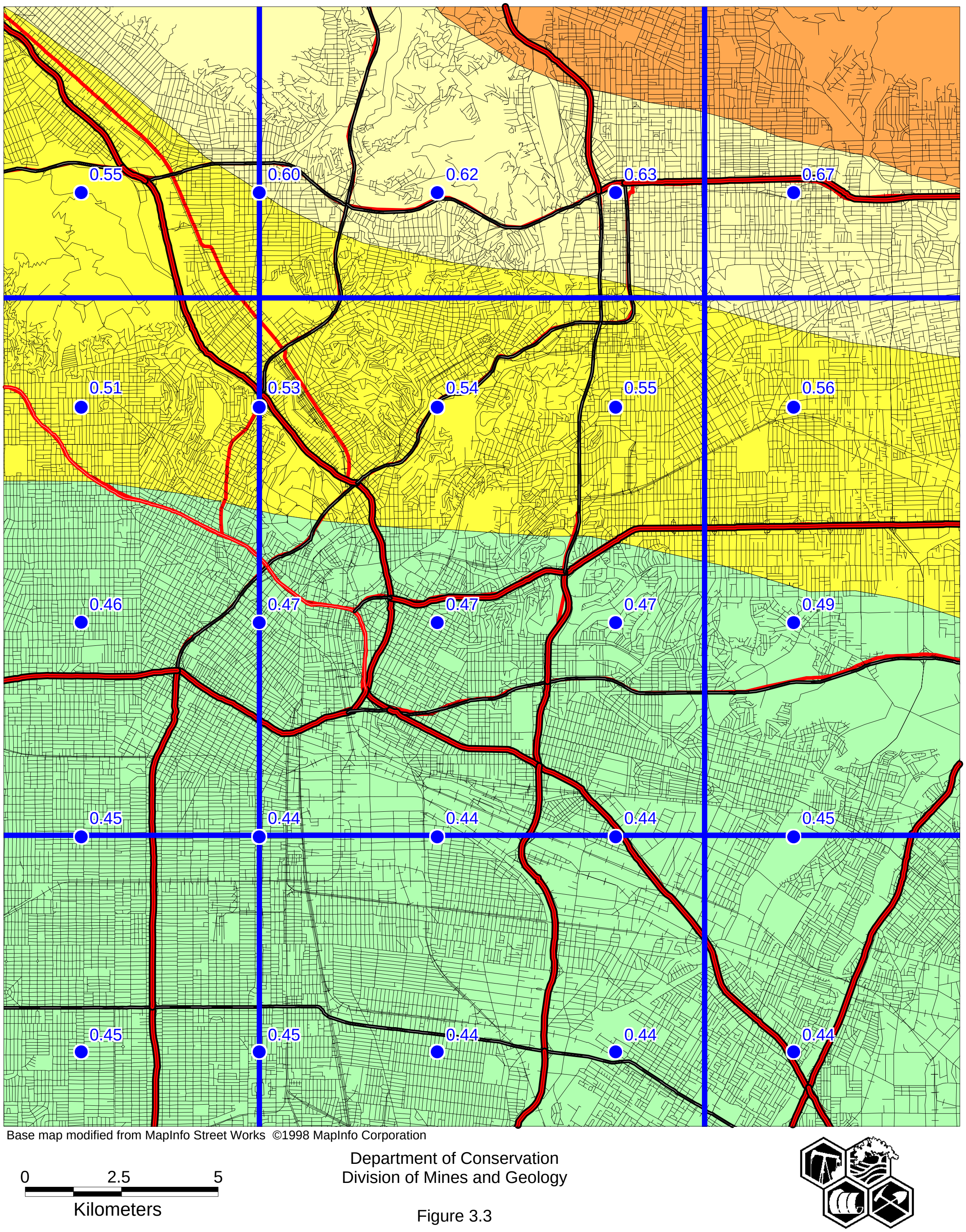

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Figure 3.3

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10% probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

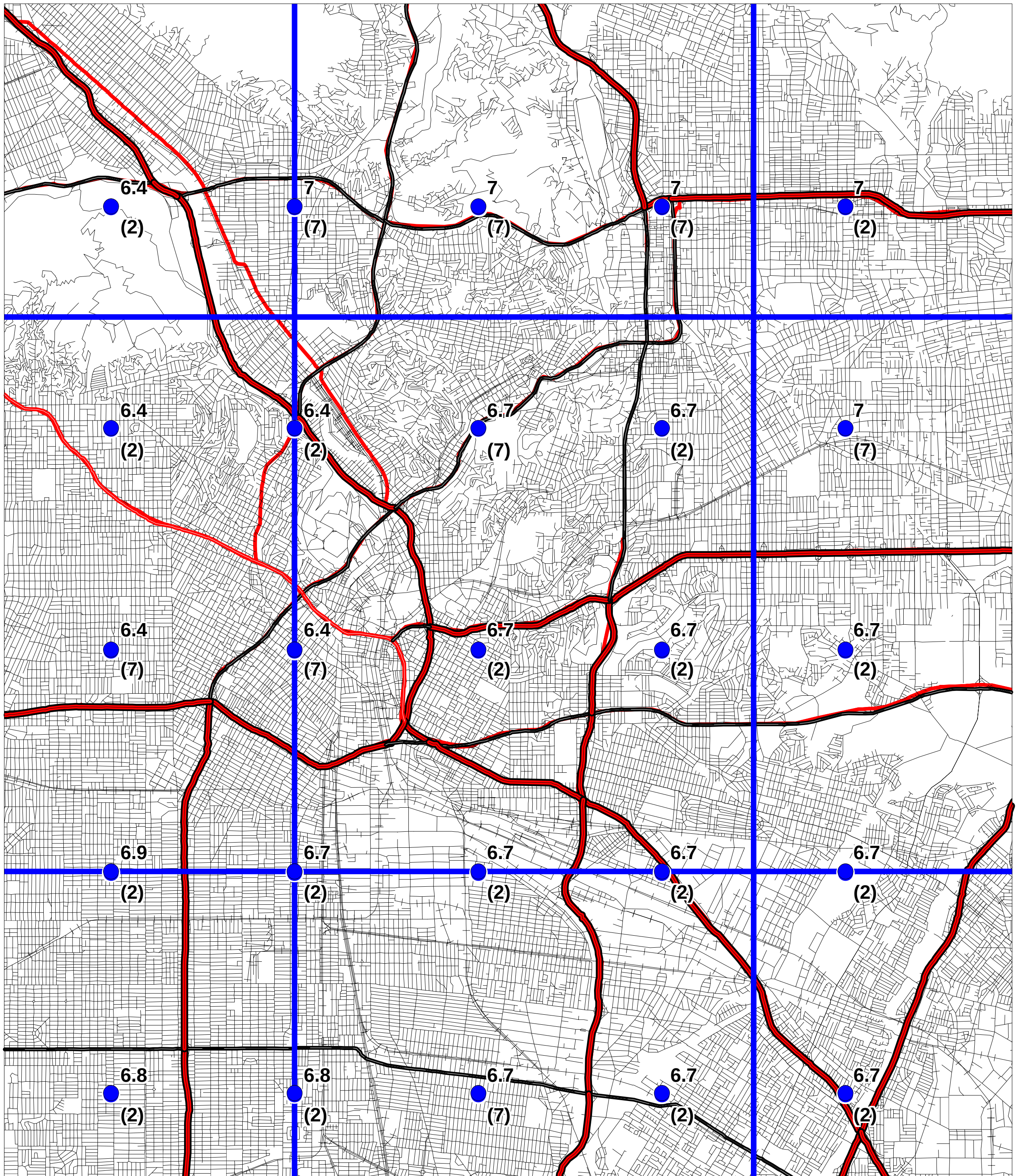
2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a

LOS ANGELES 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE
Magnitude (Mw)
(Distance (km))



Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation

0 2.5 5
Kilometers

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Figure 3.4

single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

2. Uncertainties in the hazard values have been estimated to be about +/- 50% of the ground motion value at two standard deviations (Cramer and others, 1996).

3. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not previously been recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

4. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (California State Mining and Geology Board, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the "importance" or sensitivity of the proposed building with regard to occupant safety.

REFERENCES

Boore, D.M., Joyner, W.B. and Fumal, T.E., 1997, Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra: Seismological Research Letters, v. 68, p. 154-179.

California State Mining and Geology Board, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Department of Conservation, Division of Mines and Geology, Special Publication 117, 74 p.

Campbell, K.W., 1997, Attenuation relationships for shallow crustal earthquakes based on California strong motion data: Seismological Research Letters, v. 68, p. 180-189.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange and Ventura counties, California: Bulletin of the Seismological Society of America, v. 85, no. 5, p. 1645-1649.

Cramer, C.H., Petersen, M.D. and Reichle, M.S., 1996, A Monte Carlo approach in estimating uncertainty for a seismic hazard assessment of Los Angeles, Ventura, and Orange counties, California: Bulletin of the Seismological Society of America, v. 86, p. 1681-1691.

International Conference of Building Officials, 1997, Uniform Building Code: v. 2, Structural engineering and installation standards, 492 p.

Jennings, C.W., *compiler*, 1994, Fault activity map of California and adjacent areas: California Department of Conservation, Division of Mines and Geology, California Geologic Data Map Series, Map No. 8.

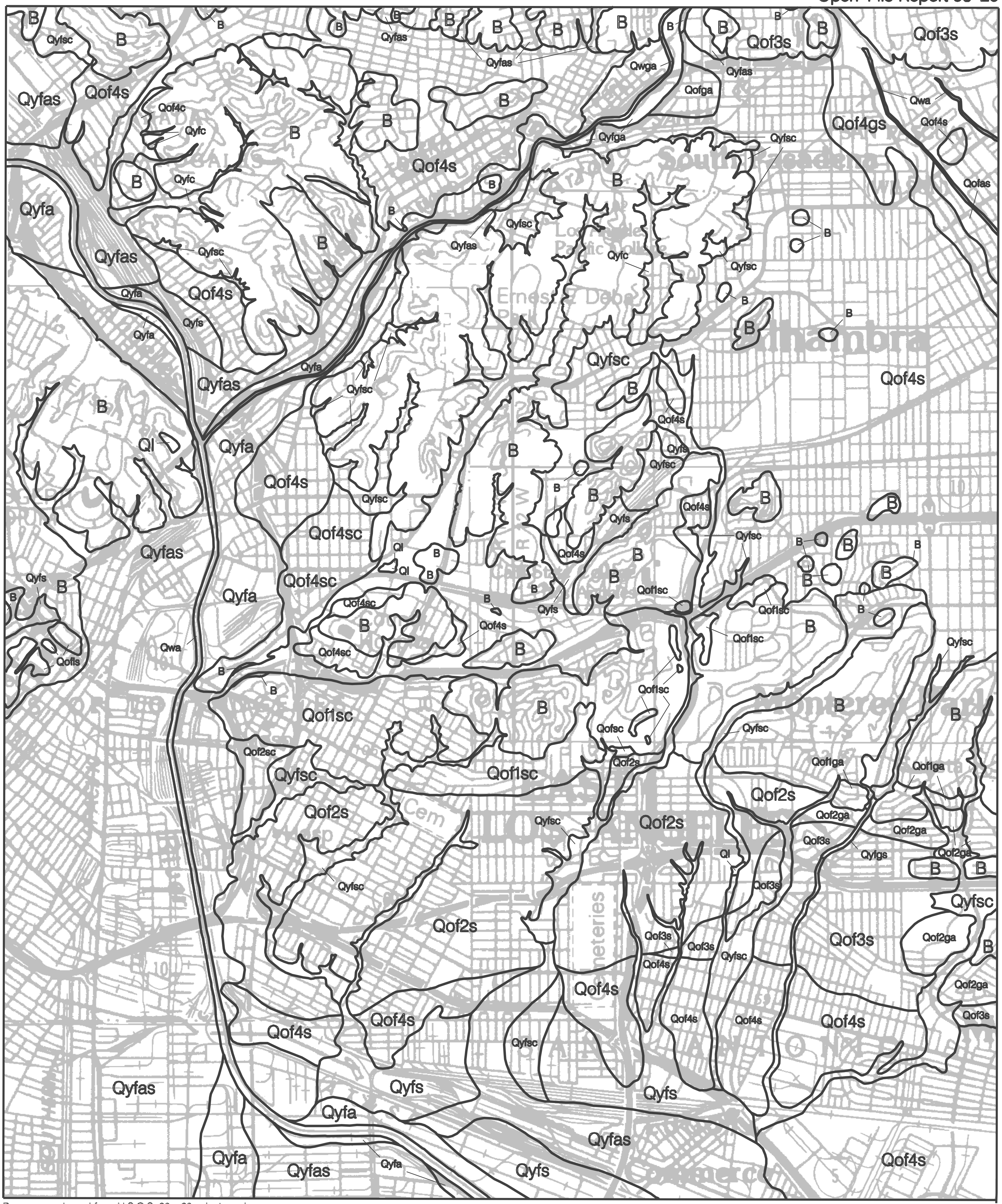
Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology Open-File Report 96-08; also U.S. Geological Survey Open-File Report 96-706, 66 p.

Sadigh, K., Chang, C.-Y., Egan, J.A., Makdisi, F. and Youngs, R.R., 1997, SEA96—A new predictive relation for earthquake ground motions in extensional tectonic regimes: Seismological Research Letters, v. 68, p. 190-198.

Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, Earthquake: Bulletin of the Seismological Society of America, v. 73, p. 863-877.

Youd, T.L. and Idriss I.M., 1997, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: Technical Report NCEER-97-0022, 40 p.

Youngs, R.R., Chiou, S.-J., Silva, W.J. and Humphrey, J.R., 1997, Stochastic point-source modeling of ground motions in the Cascadia Region: Seismological Research Letters, v. 68, p. 74-85.



Base map enlarged from U.S.G.S. 30 x 60–minute series

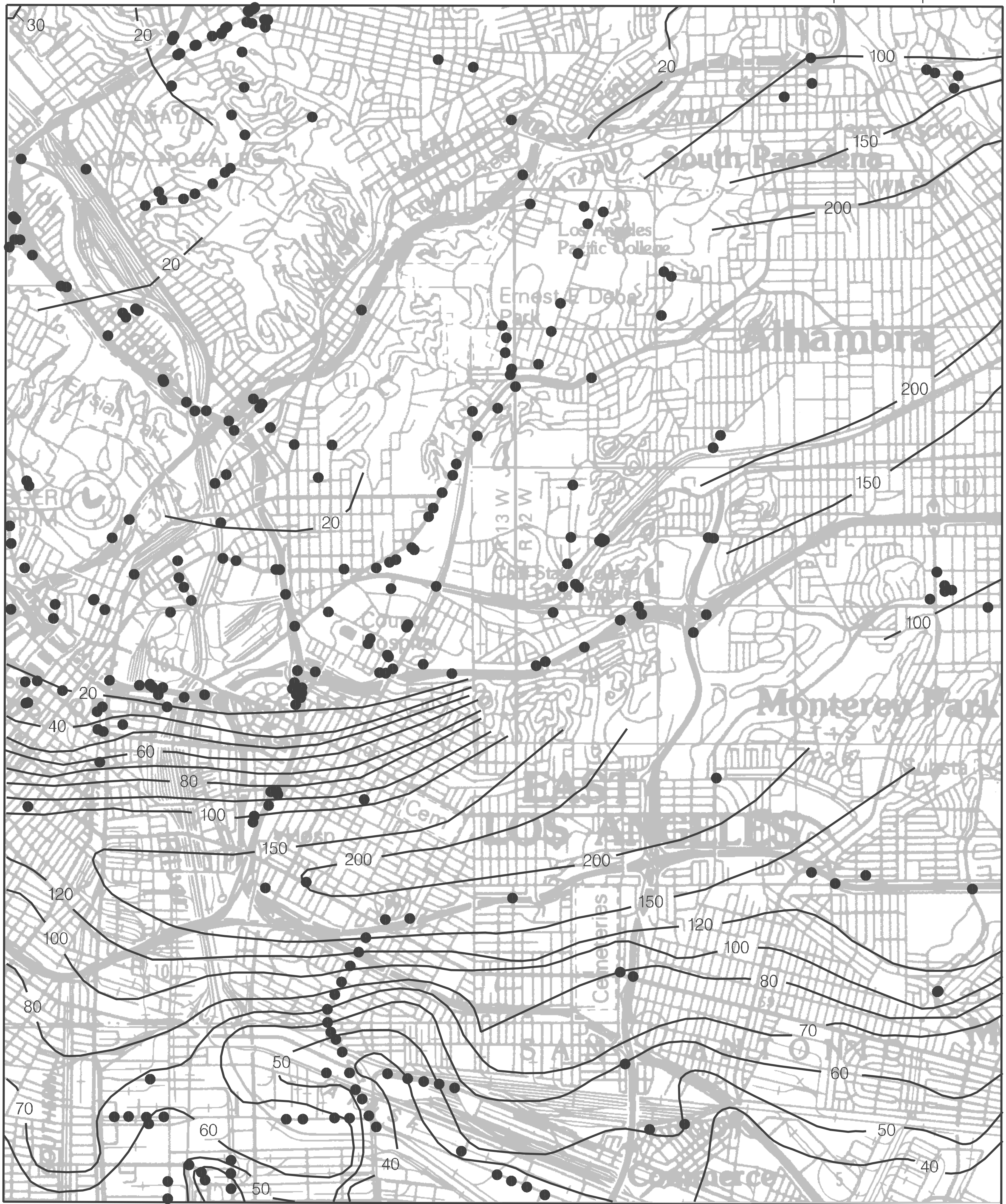
Plate 1.1 Quaternary Geologic Map of the Los Angeles Quadrangle.

See Geologic Conditions section in report for descriptions of the units.

B = Pre–Quaternary bedrock.

ONE MILE

SCALE



Base map enlarged from U.S.G.S. 30 x 60–minute series

Plate 1.2 Historically Highest Ground Water Contours and Borehole Log Data Locations, Los Angeles Quadrangle.

● Borehole Site

30 Depth to ground water in feet

ONE MILE

SCALE

Plate 2.1 Landslide inventory, Shear Test Sample Locations, Los Angeles Quadrangle.